
CSE 331

Software Design & Implementation

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Exceptions and Assertions

Outline

- General concepts about dealing with errors and failures
- Assertions: what, why, how
 - For things you believe will/should never happen
- Exceptions: what, how *in Java*
 - How to throw, catch, and declare exceptions
 - Subtyping of exceptions
 - Checked vs. unchecked exceptions
- Exceptions: why *in general*
 - For things you believe are bad and should rarely happen
 - And many other style issues
- Alternative with trade-offs: Returning special values
- Summary and review

Failure causes

Partial failure is inevitable

- Goal: prevent complete failure
- Structure your code to be reliable and understandable

Some failure causes:

1. Misuse of your code

- Precondition violation

2. Errors in your code

- Bugs, representation exposure, ...

3. Unpredictable external problems

- Out of memory, missing file, ...

What to do when something goes wrong

Fail early, fail friendly

Goal 1: *Give information about the problem*

- To the programmer – a good error message is key!
- To the client code: via exception or return-value or ...

Goal 2: *Prevent harm*

Abort: halt/crash the program

- Prevent computation (continuing could be bad)
- Perform cleanup actions, log the error, etc.

Re-try:

- Problem might be transient

Skip a subcomputation:

- Permit rest of program to continue

Fix the problem?

- *Usually* infeasible to repair from an unexpected state
- Internal problems: if you could fix it, you could prevent it

Avoiding blame for failures

A precondition prohibits misuse of your code

- Adding a precondition weakens the spec

This ducks the problem of errors-will-happen

- Mistakes in your own code
- Misuse of your code by others

Removing a precondition requires specifying more behavior

- Often a good thing, but there are tradeoffs
- Strengthens the spec
- Example: specify that an exception is thrown

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Defensive programming

Check:

- Precondition
- Postcondition
- Representation invariant
- Other properties that you know to be true

Check *statically* via reasoning and tools

Check *dynamically* via **assertions**

```
assert index >= 0;
assert items != null : "null item list argument"
assert size % 2 == 0 : "Bad size for " +
                        toString();
```

- Write assertions as you write code
- Include descriptive messages (optional but often helpful)

Enabling assertions

In Java, assertions can be enabled or disabled at runtime without recompiling

Command line:

`java -ea` runs code with assertions enabled

`java` runs code with assertions disabled (default)

IDEs: various settings

When *not* to use assertions

Don't clutter the code with useless, distracting repetition

```
x = y + 1;  
assert x == y + 1;
```

Don't perform side effects

```
assert list.remove(x); // won't happen if disabled
```

// Better:

```
boolean found = list.remove(x);  
assert found;
```

Turn them off in rare circumstances (expensive computations in production code)

- Most assertions better left enabled

assert and checkRep()

CSE 331's `checkRep()` is another dynamic check

Strategy: use `assert` in `checkRep()` to test and fail with meaningful traceback/message if trouble found

- Be sure asserts enabled when you do this!

Asserts will be enabled always for CSE 331 projects if you run things using the Gradle targets in IntelliJ

- We will enable them for grading

Expensive `checkRep()` tests

Detailed checks can be too slow in production

But complex tests can be very helpful, particularly during testing/debugging (let the computer find problems for you!)

No perfect answers; suggested strategy for `checkRep`:

- Create a static, global “debug” or “debugLevel” variable
- Run expensive tests when this is enabled
- Turn it off in graded / production code if tests are expensive

Often helpful: put expensive / complex tests in separate methods and call as needed

Square root

```
// requires:  $x \geq 0$   
// returns: approximation to square root of x  
public double sqrt(double x) {  
    ...  
}
```

Square root with assertion

```
// requires:  $x \geq 0$ 
// returns: approximation to square root of x
public double sqrt(double x) {
    assert (x >= 0.0);
    double result;
    ... compute result ...
    assert (Math.abs(result*result - x) < .0001);
    return result;
}
```

- These two assertions serve very different purposes

(Note: the Java library Math.sqrt method returns NaN for $x < 0$. We use different specifications in this lecture as examples.)

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Square root, specified for all inputs

```
// throws: IllegalArgumentException if x < 0
// returns: approximation to square root of x
public double sqrt(double x)
    throws IllegalArgumentException
{
    if (x < 0)
        throw new IllegalArgumentException();
    ...
}
```

- **throws** is part of a method signature: “it might happen”
 - Comma-separated list
- **throw** is a statement that actually causes exception-throw
 - Immediate control transfer [like **return** but different]

Using try-catch to handle exceptions

```
public double sqrt(double x)
    throws IllegalArgumentException
    ...
```

Client code:

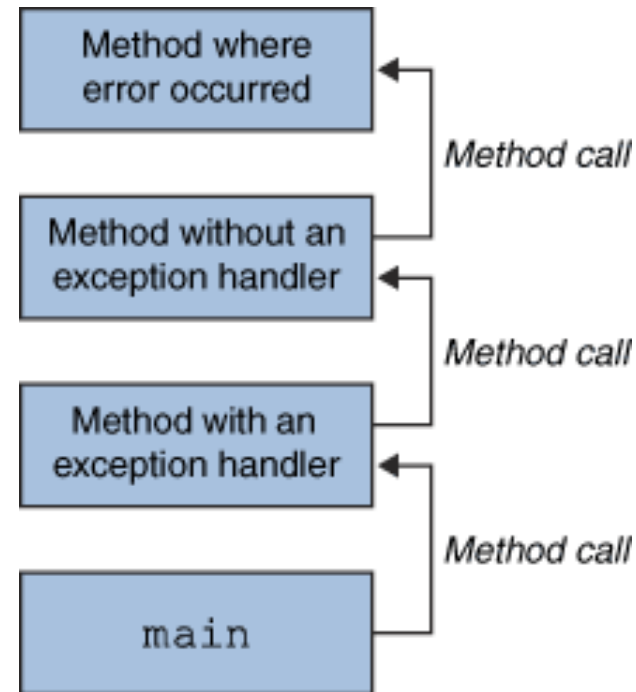
```
try {
    y = sqrt(...);
} catch (IllegalArgumentException e) {
    e.printStackTrace(); // and/or take other actions
}
```

Handled by nearest *dynamically* enclosing `try/catch`

- Top-level default handler: stack trace, program terminates

Throwing and catching

- Executing program has a stack of currently executing methods
 - Dynamic: reflects runtime order of method calls
 - No relation to static nesting of classes, packages, etc.
- When an exception is thrown, control transfers to nearest method with a *matching* catch block
 - If none found, top-level handler prints stack trace and terminates
- Exceptions allow *non-local* error handling
 - A method many levels up the stack can handle a deep error

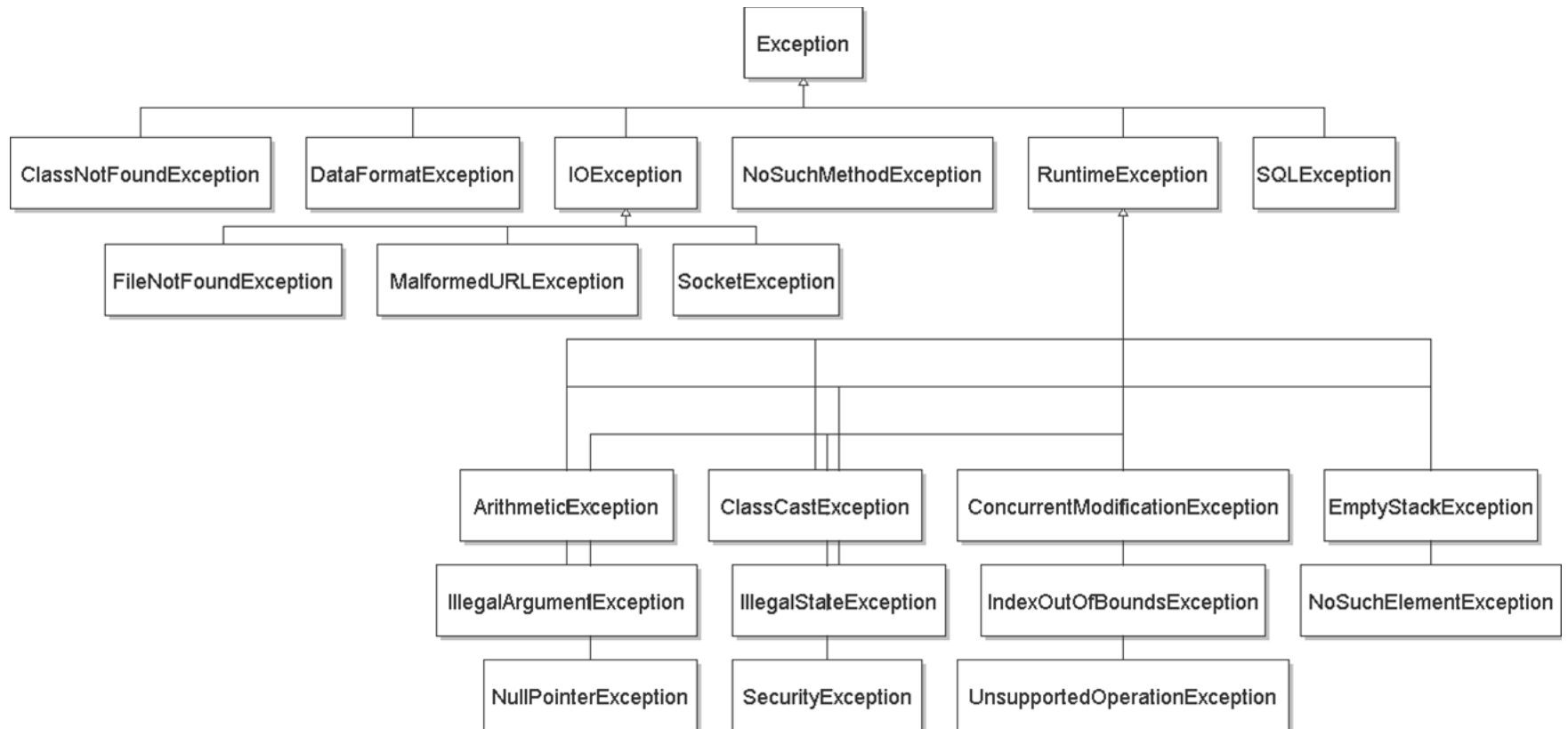


First matching `catch` clause executes

```
try {  
    code...  
} catch (FileNotFoundException fnfe) {  
    code to handle a file not found exception  
} catch (IOException ioe) {  
    code to handle any other I/O exception  
} catch (Exception e) {  
    code to handle any other exception  
}
```

- A `SocketException` would match the second block
- An `ArithmeticException` would match the third block
- Subsequent catch blocks need not be supertypes like this
 - But order matters: check for matching type in given order

Exception Hierarchy



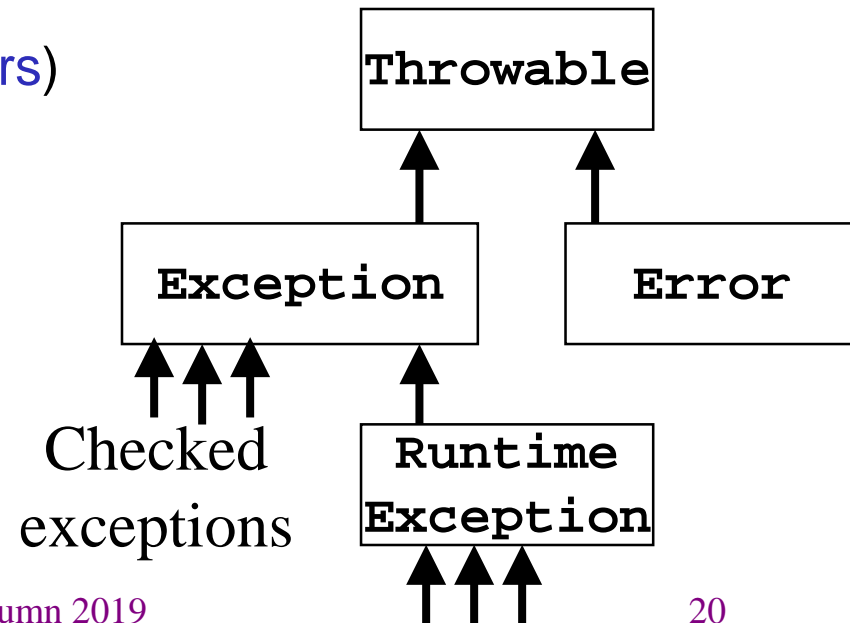
Java's checked/unchecked distinction

Checked exceptions (style: for *special cases*)

- Library: *Must* declare in signature (else type error)
- Client: Must either catch or declare (else type error)
 - Even if *you* can prove it will never happen at run time, the type system does not “believe you”
- There is guaranteed to be a dynamically enclosing catch

Unchecked exceptions (style: for *errors*)

- Library: No need to declare
- Client: No *need* to catch
- Subclasses of
`RuntimeException`
and `Error`



Checked vs. unchecked

- No perfect answer to “should possible exceptions thrown” be part of a method signature
 - So Java provided both
- Advantages to checked exceptions:
 - Static checking of method that declares it ensures no other checked exceptions get thrown
 - Static checking of caller ensures caller does not forget to check
- Disadvantages:
 - Impedes implementations and overrides
 - Often in your way when prototyping
 - Have to catch or declare even in clients where the exception is not possible

The `finally` block

`finally` block is always executed

- Whether an exception is thrown or not
- If an exception was thrown, the exception throw continues after `finally` block is done

```
try {  
    code...  
} catch (Type name) {  
    code... to handle the exception  
} finally {  
    code... to run after the try or catch finishes  
}
```

What `finally` is for

`finally` is used for common “must-always-run” or “clean-up” code

- Avoids duplicated code in catch branch[es] and after
- Avoids having to catch all exceptions

```
try {  
    // ... write to out; might throw exception  
} catch (IOException e) {  
    System.out.println("Caught IOException: "  
                        + e.getMessage());  
} finally {  
    out.close();  
}
```

When appropriate, use the try-with-resource variation on try/catch (works where things like `x.close()` are the right cleanup action)

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Why catch exceptions locally?

Failure to catch exceptions usually violates modularity

- Call chain: $A \rightarrow \text{IntegerSet.insert} \rightarrow \text{IntegerList.insert}$
- `IntegerList.insert` throws some exception
 - Implementer of `IntegerSet.insert` knows how list is being used
 - Implementer of `A` may not even know that `IntegerList` exists

Method on the stack may think that it is handling an exception raised by a different call

Better alternative: catch it and throw again

- “chaining” or “translation”
- Maybe do this even if the exception is better handled up a level
- Makes it clear to reader of code that it was not an omission

Propagating an exception

```
// returns: x such that  $ax^2 + bx + c = 0$ 
// throws: IllegalArgumentException if no real soln exists
double solveQuad(double a, double b, double c)
    throws IllegalArgumentException
{
    // No need to catch exception thrown by sqrt
    return (-b + sqrt(b*b - 4*a*c)) / (2*a);
}
```

But clients don't know if a set of arguments to `solveQuad` is illegal or legal

Exception translation

```
// returns: x such that  $ax^2 + bx + c = 0$ 
// throws: NotRealException if no real solution exists
double solveQuad(double a, double b, double c)
    throws NotRealException {
    try {
        return (-b + sqrt(b*b - 4*a*c)) / (2*a);
    } catch (IllegalArgumentException e) {
        throw new NotRealException(); // "chaining"
    }
}

class NotRealException extends Exception {
    NotRealException() { super(); }
    NotRealException(String message) { super(message); }
    NotRealException(Throwable cause) { super(cause); }
    NotRealException(String msg, Throwable c) { super(msg, c); }
}
```

Exceptions as non-local control flow

```
void compile() {  
    try {  
        parse();  
        typecheck();  
        optimize();  
        generate():  
    } catch (RuntimeException e) {  
        Logger.log("Failed: " + e.getMessage());  
    }  
}
```

- Not common – usually bad style, particularly at small scale
- Java/C++, etc. exceptions are expensive if thrown/caught
- Reserve exceptions for exceptional conditions

Two distinct uses of exceptions

- Errors
 - Unexpected
 - Should be rare with well-written client and library
 - Can be the client's fault or the library's
 - Usually unrecoverable
- Special results
 - Expected but not the common case
 - Unpredictable or unpreventable by client
 - Client can and should do something about it

Handling exceptions

- Failures
 - Usually can't recover
 - If condition not checked, exception propagates up the stack
 - The top-level handler prints the stack trace
 - Unchecked exceptions the better choice (else many methods have to declare they could throw it)
- Special results
 - Take special action and continue computing
 - Should always check for this condition
 - Should handle locally by code that knows how to continue
 - Checked exceptions the better choice (encourages local handling)

Don't ignore exceptions

Effective Java Tip #77 [65 2nd]: Don't ignore exceptions

Empty catch block is (common) poor style – often done to get code to compile despite checked exceptions

- Worse reason: to silently hide an error

```
try {  
    readFile(filename);  
} catch (IOException e) {} // silent failure
```

At a minimum, print out the exception so you know it happened

- And exit if that's appropriate for the application

```
} catch (IOException e) {  
    e.printStackTrace();  
    System.exit(1);  
}
```

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Informing the client of a problem

Special value:

- `null` for `Map.get`
- `-1` for `indexOf`
- `NaN` for `sqrt` of negative number

Advantages:

- For a normal-ish, common case, it “is” the result
- Less verbose clients than try/catch machinery

Disadvantages:

- Error-prone: Callers forget to check, forget spec, etc.
- Need “extra” result: Doesn’t work if every result could be real
 - Example: if a map could store `null` keys
- Has to be propagated manually one call at a time

General Java style advice: Exceptions for exceptional conditions

- Up for debate if `indexOf` not-present-value is exceptional

Special values in C/C++/others

- For errors and exceptional conditions in Java, use exceptions!
- But C doesn't have exceptions and some C++ projects avoid them
- Over decades, a common idiom has emerged
 - Error-prone but you can get used to it ☹
 - Affects how you read code
 - Put “results” in “out-parameters”
 - Result is a boolean (int in C) to indicate success or failure

```
type result;
```

```
if(!computeSomething(&result)) { ... return 1; }
```

```
// no "exception", use result
```

- Bad, but less bad than error-code-in-global-variable

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Exceptions and specifications

Use an **exception** (complete specification) when

- Used in a broad or unpredictable context
- Checking the condition is feasible

Use a **precondition** (partial specification) when

- Checking would be prohibitive
 - E.g., requiring that a list be sorted for binary search
- Used in a narrow context in which calls can be checked
- Avoid preconditions in public APIs because (i) caller might violate precondition, (ii) program can fail in dangerous or inscrutable ways

Use a **special value** when

- It is a reasonable common-ish situation
- Clients are likely (?) to remember to check for it

Use an **assertion** for internal consistency checks that should not fail

Exceptions: concluded

Use *checked* exceptions most of the time

- Static checking is helpful

Use *unchecked* exceptions if

- Callers can guarantee the exception cannot occur, or
- Callers can't do anything about it

Handle exceptions sooner rather than later

Not all exceptions are errors

- Example: File not found

Read: *Effective Java*, Chapter 10 [2nd edition ch. 9]

- A whole chapter? Exception-handling design matters!